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Memo

Date: *Oct. 24, 2014*

To: *RSC, S. Pontieri, and S. Smith*

From: *D. Beavis* DB

Subject: *BLIP Penetrations from the BLIP Spur to the Control Room*

The proton transport in the BLIP spur is being modified for the incorporation of the beam raster system for BLIP. The upgrade will require existing penetrations that have been plugged to be opened to provide a means of routing cables from the BLIP control room to the magnets and instrumentation in the BLIP spur. This report provides details of the design of the shielding for these penetrations.

The current ASE for the Linac allows operation of $5.5*10^{18}$ protons per hour at 200 MeV. The shielding for the penetrations has been analyzed for this beam current assuming that the beam can fault continuously for an hour near the penetrations. It is not likely for large beam faults to have durations for large portions of an hour. Items which limit beam fault duration will be discussed.

There are a series of penetrations from the tunnel to the BLIP control room. There are six two-inch diameter tubes, three six-inch diameter tubes, and one ten-inch diameter tube. The calculations will focus on the ten inch diameter tube and then the results will be scaled to the smaller tubes. The concept of placing doglegged conduits though plugs inserted into the pipes was abandoned to allow the potential use of the largest possible area of the penetration. The shielding will be placed around and above the penetration on the existing floor.

The Monte Carlo Program[1] MCNPX 2.7.C was used in three stages to calculate the radiation through the penetration and then through the shield. Dividing the problem into sections reduces computer time for calculations, although it requires more time to setup[2] the complete problem. The first phase is to calculate the initial radiation that challenges the surface where the penetrations enter the BLIP tunnel. The simulation assumes that a 200 MeV proton beam strikes a steel rod 5cm in radius[3] and 60 cm long. The particle fluences were tallied at a radius of two meters in one meter bins along the beam direction[4]. The neutron results are shown in Figure I.

[1] Reference
[2] It also increases the chance for errors in judgment and other mistakes in the transition from one phase of results to the next calculation.
[3] The results for a steel rod with a 1 cm radius have smaller peak and backward fluences, but eventually higher fluences in the forward direction.
[4] No shielding is present in this phase to avoid the scatter of particles off the shielding, which will impact the low portions of the particle energy spectrum.

The peak neutron fluence is $1.2*10^{-6}$ n/cm^2 per proton. The particle fluences were tallied in approximately 20 energy bins. The neutrons dominate the radiation that will exit the penetration so that only the neutron spectra are used in the second stage of the calculation.

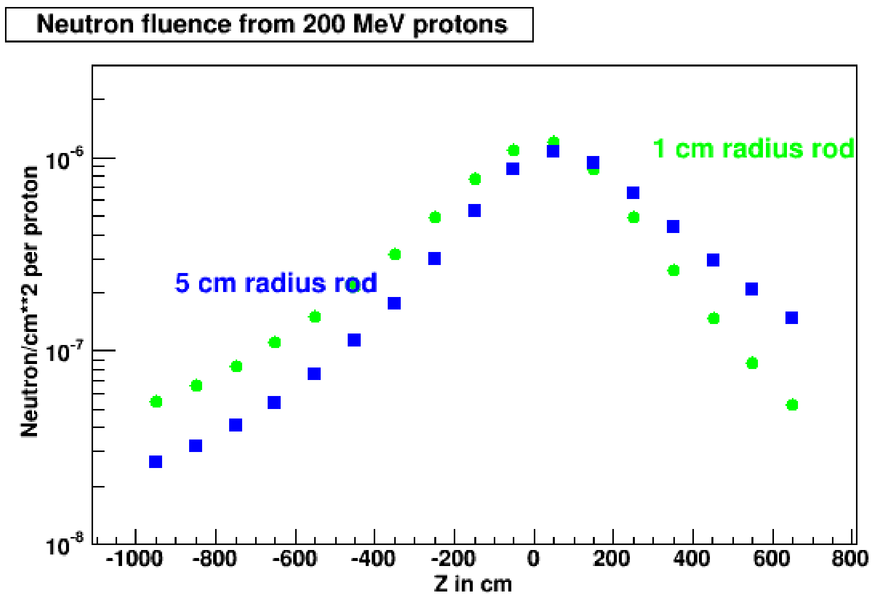

Figure I: Neutron fluence for a 200 MeV proton beam striking a steel rod 160 cm long as a function of z. The steel rod has a radius of 1 cm (blue points) and 5 cm (green points). The rod starts at z=0 cm. Fluences were tallied at a radius of 200 cm.

The second stage has a uniform neutron source illuminate a solid angle of 1.56 steradians centered about the penetration opening. The neutrons are generated at a source point location that is 50 cm upstream of the penetration and 5 feet off axis and 5 feet below the ceiling of the blip tunnel. The neutron energy is selected from the energy distribution obtained in the first phase. The elevation view of the linac tunnel is shown in Figure II. The ceiling is 50 cm of light concrete followed by 590 cm of soil[5]. The neutron fluence and dose rate are tallied at selected locations along the axis of the ten inch diameter penetration. The results for the second phase are normalized by applying a factor to make the results agree for the fluence obtained in the first phase at the beginning of the penetration. The neutron dose attenuation as a function of distance along the penetration is shown in Figure III and compared with the labyrinth formula[6] of Goebel et. al. The neutron dose is attenuated by a factor of $1.8*10^{-5}$ over the length of the penetration. The labyrinth formula gives excellent results and for large distance becomes conservative. A neutron dose rate of 2.25 rem/hr results[7] from a continuous beam loss at the ASE limit out of the empty penetration at floor level.

[5] The density of the soil is 1.8 g/cm^2.
[6] Goebel et. al.
[7] After the calculations it was noted that the penetrations are four feet off axis and not five. This results in a small increase in the dose rate and is incorporated in the quoted number.

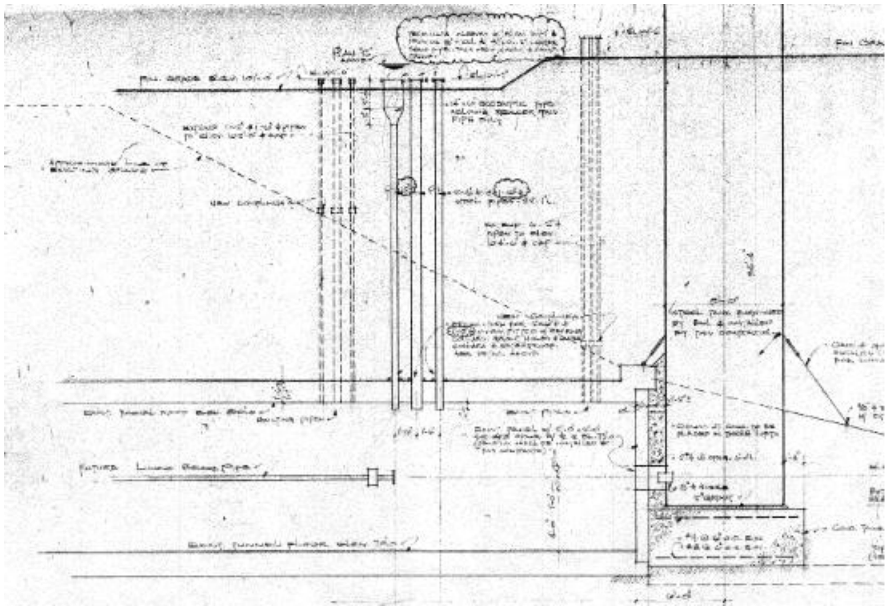

Figure II: Elevation view of the penetrations from the BLIP spur to the BLIP control room.

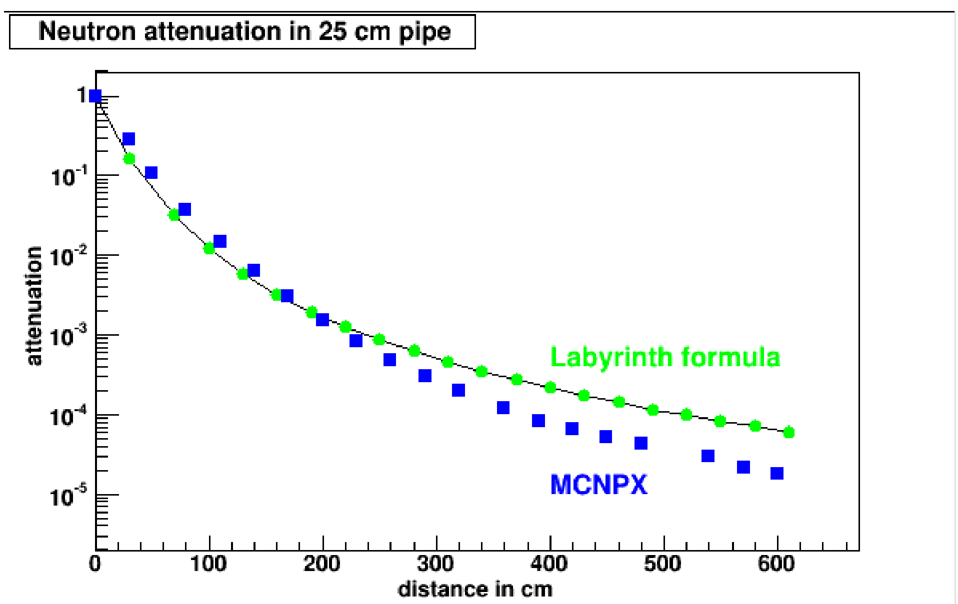

Figure III: The neutron attenuation in a 25 cm diameter steel pipe. The neutrons are created by protons striking a steel rod. The pipe is surrounded by soil expect the initial 50 cm which is light concrete.

The third phase of the calculation estimates the dose rate after the shielding that is placed over and on the sides of the penetration exit. The shielding should reduce the dose rate by a factor of approximately 100 to achieve acceptable doses in a beam fault. The initial dimensions and types of shielding were selected using the table of attenuation lengths provided by P.K. Job and W. R.

Casey[8], along with some judgment for the diffusion that is not taken into account in these broad beam attenuation factors. Figure IV shows the top of the penetration in elevation view. The shield was chosen to have 15 cm (six inches) of steel followed by 15 cm of poly on top of the steel. On the sides are 30 cm of light concrete. The concrete is not necessary but prevents personnel from reaching inside to the penetration and reduces the potential dose to personnel in the area. The model was also run without the side concrete to estimate the dose out the cable tray, which makes a hole in the side shield. To obtain a better energy spectrum for the neutrons the fluence was tallied as a function of energy 300 cm below control room floor and then an appropriate solid angle relative to the vertical was selected to achieve an appropriate attenuation to the surface. The dose rates were then tallied on the sides of the shield and the top for a beam loss at the ASE limit. The dose rates[9] include an increase of 50% to account for scattered neutrons off the tunnel floor into the penetration and the production of gamma rays (10%) generated in the shield. The results are presented in Table I.

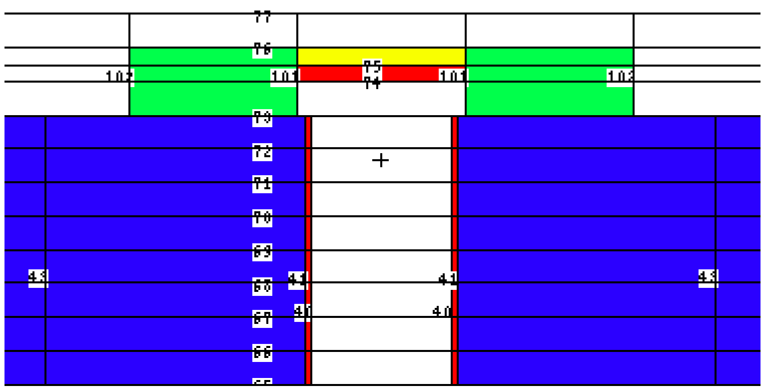

Figure IV: The model for the penetration shielding. The blue is soil, the red is steel, the green is light concrete, and the yellow is polyethylene.

The dose rate one foot above the shield is 40 mrem/hr over the central portion of the shield. The control room is posted as a Controlled Area with a TLD required. The potential exposure in a scrapping incident would be expected to be much less than the results presented in Table I. There are several processes that are expected to limit the duration of large beam losses. The Fast Beam Interrupt[10] (FBI) will automatically stop the beam if the transmission efficiency is less than 50%. The beam pipe and collimators have thermal couples attached, which limits the temperature increase from beam scrapping. The collimators have a temperature limit of 125 degrees C, which corresponds to a 0.3% beam loss. The thermal couples are part of the FBI. The Linac beam current is typically monitored by operations staff to ensure that the beam delivery to BLIP targets is within the requested range. Finally it is noted that the ASE limit is not expected to be achievable until the Linac doubling upgrade is complete in several years.Therefore, there is

[8] P.K. Job and W.R. Casey, "Preliminary Radiological Considerations for the Design and Operation of NSLSII Linac", NSLSII Technical Note 00012, July 25, 2006. See Table I.
[9] This is equivalent to a exit dose rate of 3.4 rem/hr out of the penetration.
[10] Based on a conversation with D. Raparia, the Liaison Physicist for the Linac.

considerable defense in depth that make it reasonable to assume that the dose for a scrapping fault will be much less than 40 mrem/incident.

Table I: Dose Rate outside the 10 inch Penetration Shielding for a loss of $5.5*10^{18}$ p/hr

Radius (cm)	Contact dose rate (mrem/hr)	Dose rate at 1 foot (mrem/hr)	Surface
<15	80	40	top
15-45	15	12	top
45-75	9	5	top
45	14		side
75		5	side
75		23	side –no side shielding

The exit dose per proton for the smaller penetrations (15 cm and 5 cm) can be scaled from the results of the 25 cm diameter penetration. The exit dose rates for a full beam loss are 740 mrem/hr for the 15 cm diameter penetrations and 220 mrem/hr for the 5 cm diameter penetrations. The change in dose was examined as a function of shielding thickness[11]. A shield with half the thickness of the one suggested above will reduce the dose from a 15 cm diameter penetration to dose rates of about 30 mrem/hr directly over the penetration at a distance of one foot above the shield. The two inch diameter penetrations encircle a six inch diameter penetration so there is no reason to calculate a shield for those. The shield for the six inch diameter penetration should span over the adjacent two inch diameter penetrations.

It is concluded that the shielding proposed should provide adequate dose reduction in the event of beam scrapping in the proton transport near the penetrations. A beam fault study should be considered to verify the design.

[11] The ratio of the shielding materials was kept fixed. This calculation was done by changing the density of the shields rather than changeingthe actual thickness.